Perspectives of Hydrogen Fuel Cells in Aviation

Mamadjanov Lochinbek Yusupovich,
The deputy head on educational affairs
of the Higher military aviation school
the Republic of Uzbekistan

Annotation: This article deals with perspectives of hydrogen fuel cells in aviation sphere. It should be noted that Hydrogen fuel cells are emerging as a high-potential technology that offers significant energy efficiency and decarbonisation benefits to a range of industries – including automotive and heavy transport. This paper presents and discusses the classification, working principles, characteristics, and critical technologies of hydrogen fuel cells. Additionally, future technologies and development, including the high-power density motors, converters, power supplies, are discussed for the hydrogen fuel cells in aviation industry.

Key words: hydrogen fuel, potential technology, aviation industry, converter, power supply, critical technology, working principles.

I. Introduction

Decarbonization is a major challenge for aviation. The aviation sector emits more than 900 million tons of carbon dioxide (CO_2) per year. Assuming industry growth of 3 to 4 percent per annum (p.a.) and efficiency improvement of 2 percent p.a., emissions would more than double by 2050. In the same time period, the Air Transport Action Group (ATAG) committed to 50 percent CO_2 emission reduction (compared to 2005) and the European Union (EU) set with the Green Deal a target to become carbon neutral. Beyond CO_2, aircraft impact the climate through emissions of nitrogen oxides (NO_x), soot, and water vapor, which create contrails and cirrus clouds. Therefore, the “full” contribution to global warming is significantly higher than just CO_2 emissions alone.

To reduce climate impact, the industry will have to introduce further levers such as radically new technology, significantly scale sustainable aviation fuels (SAF) such as synthetic fuel (synfuel), temporarily rely on offsets in large quantities, or rely on a combination thereof. H_2 propulsion is one such technology. Developed with input from leading companies and research institutes, it projects the technological development of H_2 combustion and fuel cell-powered propulsion, evaluates their technical and economic feasibility, compares them to synfuel, and considers implications on aircraft design, airport infrastructure, and fuel supply chains.

Bold steps need to be taken urgently to initiate a path towards decarbonization through hydrogen. The industry needs to change trajectory today, as commercialization and certification of aircraft can take more than 10 years, and substantial fleet replacement another 10 years. To transition to a new propulsion technology, a sector roadmap to reduce climate impact, a step-up in Research & Innovation (R&I) activity and funding, and a long-term policy framework will be required. The sector roadmap needs to set the ambition level, align standards, derive safety measures, coordinate infrastructure build-up, overcome market failures and encourage first movers. An inspiring mid-term target could be the introduction of a H_2-powered short-range aircraft before 2035. R&I activities and funding should focus on four key areas: LH_2 fuel and propulsion components, aircraft systems, infrastructure ramp-up, and the regulatory framework. The long-term policy framework should lay out the rail guards for the sector, including how climate impact will be measured and the roadmap will be implemented. The European Union could first target commuter, regional, and short-range flights as they are covered within its jurisdiction, and then expand this to medium- and long-range aircraft together with its international partners

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II. Methods And Results

In 1838, judge-turned-scientist Sir William Grove came up with a novel idea: to construct a cell consisting of two separate sealed compartments, each of which was fed by either hydrogen or oxygen gas. At the time, he called his invention a “gas voltaic battery.” Unfortunately, it did not produce enough electricity to be of much use. It remained a scientific curiosity until the 20th century, when English engineer Francis Thomas Bacon matured the original idea to develop the world’s very first hydrogen-oxygen fuel cell in 1932.

Bacon’s fuel cell was such a success that it has been used by the space industry to power satellites and rockets for space exploration programmes, including Apollo 11, since the 1960s. As the story goes, then-US President Richard Nixon famously said: "Without you Tom, we wouldn't have gotten to the moon.”

Today, hydrogen fuel cell technology is being used for a variety of applications, including to:

provide emergency backup power to critical facilities like hospitals;

replace grid electricity for critical-load facilities like data centres;

power a variety of transportation modes such as cars, buses, trains and forklifts.

Tomorrow it could potentially power everything from low-carbon cities and regions to portable computing devices to future zero-emission aircraft.

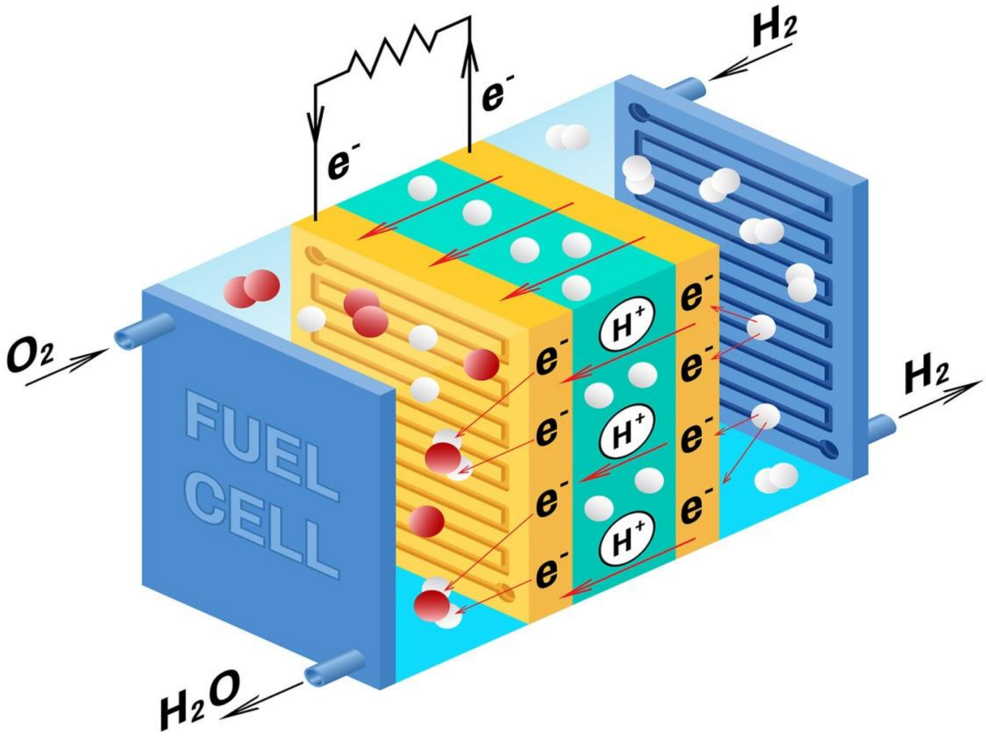
Similar to batteries, a fuel cell is a device that converts energy stored in molecules into electricity through an electrochemical reaction. Composed of two electrodes (an anode and a cathode) separated by an electrolyte membrane, a typical hydrogen fuel cell works in the following way:

Hydrogen enters the fuel cell via the anode. Here, hydrogen atoms react with a catalyst and split into electrons and protons. Oxygen from the ambient air enters on the other side through the cathode.

The positively charged protons pass through the porous electrolyte membrane to the cathode. The negatively charged electrons flow out of the cell and generate an electric current, which can be used, for example, to power an electric or hybrid-electric propulsion system.

In the cathode, the protons and oxygen then combine to produce water.

Picture 1.



Because fuel cells generate electricity through an electrochemical reaction, they are a clean source of power. In fact, fuel cells that use pure hydrogen are carbon-free. Some other key advantages of fuel cells include the following:

Unlike batteries that need to be recharged, fuel cells can continue to generate electricity as long as a fuel source (hydrogen) is provided.

Individual fuel cells can be “stacked” to form larger systems capable of producing more power, thereby allowing scalability. A single fuel cell can produce enough voltage to power small applications, while fuel cell stacks can be combined to create large-scale, multi-megawatt installations. Because there are no moving parts, fuel cells are silent and highly reliable.

As this article has shown, hydrogen propulsion has the potential to be a significant part of the propulsion mix by 2050 and to play a key role in the decarbonization of aviation. To do so requires a step-up in research, innovation, and development activity to develop the underlying technologies, integrate them into airplanes, and develop the necessary infrastructure. These research activities will also yield better insights into the feasibility, economics, and climate impact of future technologies. They will address many of the uncertainties identified in this study, validate and invalidate the taken assumptions, and help to refine this roadmap towards decarbonized aviation.

There is an urgent need to act now. Depending on the size of the aircraft the introduction of larger new aircraft typically takes around 15 to 20 years, and broad deployment across the fleet another 10 years. The last generation of short-range aircraft, responsible for roughly one quarter of total climate impact of the sector, was introduced around 2015 (e.g., the A320neo family of aircraft). This opens a window of opportunity between 2030 and 2035 for a new, decarbonized aircraft in this segment. The next generation in this segment would then be expected only between 2045 and 2050 which would be too late to achieve the decarbonization objectives for this segment set by the EU and ATAG targets. Regional and/or commuter pilots could be introduced before, and the short-range aircraft could become a stepping stone towards introduction in medium-range aircraft.

III. Discussion

Over the last two decades, the automotive and space industries have been at the forefront of maturing hydrogen fuel cell technology. For example, fuel cell electric vehicles (FCEVs) have gone through several stages of development to prove their efficiency, safety and reliability, offering the exciting potential for longer range, larger carrying capacity, and faster refuelling times than traditional electric vehicles. And hydrogen fuel cells have been used by the space industry to power auxiliary electric systems on board spacecraft for years. This same technology is now inspiring aeronautical engineers to consider new ways to power electrical systems on board future aircraft.

In fact, Airbus’ ZEROe concept aircraft is expected to use hydrogen fuel cells to create electrical power that complements the modified gas-turbine engines, resulting in a highly efficient hybrid-electric propulsion system. To further explore the possibilities of fuel cell propulsion systems for aviation, Airbus has entered into a strategic partnership* with ElringKlinger, a company with over 20 years of experience as both a fuel cell system and component supplier.

“This partnership will contribute to growing our in-house expertise in alternative-propulsion systems,” says Glenn Llewellyn, Airbus VP of Zero-Emission Aircraft. “Today, Airbus has significant know-how in electric propulsion and fuel cells thanks to work carried out at our E-Aircraft System House and currently taking place at the ZAL in Hamburg. This partnership will be a phenomenal acceleration in bringing hydrogen fuel cells to future aircraft.”

The agreement involves co-developing and co-validating aviation-compatible fuel cell stacks. In particular, testing the power density of fuel cell stacks for aircraft will be a key focus area.

“Battery-powered propulsion to fuel larger aircraft over longer distances is not possible with today’s technology,” explains Matthieu Thomas, ZEROe Aircraft Lead Architect. “Hydrogen fuel cells could be a great alternative because they can generate – with zero emissions – significantly more power and energy for a given weight. This makes fuel cells an extremely interesting technology to achieve our ambitions.”

The immediate priority for components is to develop and engineer lightweight tank systems, reliable fuel distribution components, H_2 propulsion turbines with low-NO_x emissions and long lifetimes, and high-power fuel cell systems. To guide research and development, certification requirements must be decided for each component.

The LH_2 tank with appropriate volume and weight is a key enabler of technologically feasible and economic H_2 -powered aviation. A sensitivity analysis shows how the economics depend on the gravimetric tank index.

This is especially important for the long-range segment: an index increase from 38 percent to 55 percent would make LH_2 -powered aircraft competitive with synfuel-powered aircraft thanks to a 44 percent decrease in CO_2 equivalent abatement costs. To achieve a gravimetric index of 35 percent for a short-range aircraft and 38 percent or more for a long-range aircraft, the R&I of LH_2 tanks needs to link strongly to that of aircraft manufacturers and certification authorities. It should focus on:

- Synergistic tank design and integration into fuselage – testing new and also non-cylindrical or spherical shapes as well as advanced materials for safe and light tank walls.
- Safety and certification procedures and requirements adapted to LH_2 tank standards including specified boil-off requirements for on-ground handling. If no or reduced boil-off requirements on ground can be adjusted to still ensure safe ground handling or storage of aircraft, tank walls could be built lighter.
- Reliable components with focus on cooling equipment such as cryogenic pumps, pipes, and valves, and sensors including condition-monitoring capabilities. These components and the tank walls should also be designed to last at least as long as the aircraft's lifetime, with the least amount of maintenance possible.

Research on how to increase the power density of fuel cells by threefold is crucial for larger fuel-cell aircraft designs. If fuel cells' power density cannot be increased, the energy-saving potential of the concept studies on commuter, regional, and short-range aircraft cannot be realized.

A major limiting factor of fuel cell systems with higher installed power – more than 10 to 20 megawatts – is the resulting rise in heat, which requires large, heavy heat exchangers to cool the system. Consequently, fuel cell manufacturers should focus on:

- Scaling of systems through synergies in weight and cooling due to potentially optimized modularization, higher operating temperatures, and light heat exchangers.
- Reliable components with an extended lifetime (of about 25,000 operating hours or more) by optimizing operation regimes, and using lightweight materials.
- In-flight H_2O treatment on-board in order to minimize climate impact.

IV. Conclusion

Another key to unlocking the potential of LH_2 aviation is developing the necessary refueling infrastructure. Most of the required technologies are commercially available today, so the challenge lies mainly in scaling and building parallel infrastructures during the transition to new aircraft systems. Nevertheless, some critical R&I challenges need to be resolved. The outcome of tackling these challenges could "make or break" the competitiveness of LH_2 flight.

In the short term, new refueling strategies and technologies must accelerate the refueling process to compete with conventional refueling rates. At the same time, the industry must establish bespoke safety measures for LH_2 and review their potential impact on parallel operations. The airport refueling set-up may also need to be reviewed in light of parallel infrastructure needs. Over the medium and long terms, installing at-scale LH_2 supply and liquefication at airports will be a key R&D challenge. In the longer term, it may prove fruitful to explore if and how LH_2 hydrant refueling systems could play a role in at-scale LH_2 refueling.

While hydrogen fuel cell technology to power alternative-propulsion systems is still new to aviation, cross-industry collaboration, like the strategic partnership between Airbus and ElringKlinger, will be essential to maturing the technology's potential in the years to come.

In summary, hydrogen propulsion has significant, so far underestimated potential to reduce the climate impact of aviation and contribute to decarbonization objectives. To reap this potential, we must develop and deploy new technologies across the board. R&I must be immediately accelerated before we can transition the aviation sector and the industry into a more efficient and decarbonized future.

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